Synthetic Aperture Sonar (SAS) and Acoustic Templates for the Detection and Classification of Underwater Munitions

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14. ABSTRACT

This presentation will present a series of monostatic and bistatic acoustic scattering measurements were conducted to investigate discrimination and classification capabilities based on the acoustic response of targets for underwater unexploded ordnance (UXO) applications. The measurements were performed during March 2010 and are referred to as the Pond Experiment 2010 (PondEx10), where the fresh water pond contained a sand sediment. The measurements utilized a rail system with a mobile tower and a stationary sonar tower. Each tower is instrumented with receivers while the sources are located on the mobile tower. For PondEx10, eleven targets were deployed at two distinct ground ranges from the mobile tower system. Acoustic data were initially processed using synthetic aperture sonar (SAS) techniques and the data were further processed to generate acoustic templates for the target strength as a function of frequency and aspect angle. Preliminary results of the processing of data collected from proud targets are presented. Also presented are the results associated with a processing technique that permits isolation of the response of an individual target, which is in close proximity to other targets. [Research supported by The Strategic Environmental Research and Development Program under projects MR-1665 and MR-1666 and the Office of Naval Research.]

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SYNTHETIC APERTURE SONAR (SAS) AND ACOUSTIC TEMPLATES FOR THE DETECTION AND CLASSIFICATION OF UNDERWATER MUNITIONS

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This presentation will present a series of monostatic and bistatic acoustic scattering measurements were conducted to investigate discrimination and classification capabilities based on the acoustic response of targets for underwater unexploded ordnance (UXO) applications. The measurements were performed during March 2010 and are referred to as the Pond Experiment 2010 (PondEx10), where the fresh water pond contained a sand sediment. The measurements utilized a rail system with a mobile tower and a stationary sonar tower. Each tower is instrumented with receivers while the sources are located on the mobile tower. For PondEx10, eleven targets were deployed at two distinct ground ranges from the mobile tower system. Acoustic data were initially processed using synthetic aperture sonar (SAS) techniques, and the data were further processed to generate acoustic templates for the target strength as a function of frequency and aspect angle. Preliminary results of the processing of data collected from proud targets are presented. Also presented are the results associated with a processing technique that permits isolation of the response of an individual target, which is in close proximity to other targets. [Research supported by The Strategic Environmental Research and Development Program under projects MR-1665 and MR-1666 and the Office of Naval Research.]

Outline of Presentation

- Hypothesis and technical objectives of the research
- Pond Experiment 2010 (PondEx10) environment
- Equipment and experimental layout
- Deployed munitions and scientific targets
- Experimental results and some data-model comparisons
- Conclusions and future work

Hypothesis and Technical Objectives

Central hypothesis: *The environment can alter the acoustic response of an unexploded ordnance (UXO) significantly, so the environment must be taken into account when developing robust detection and classification strategies.*

Technical objectives include

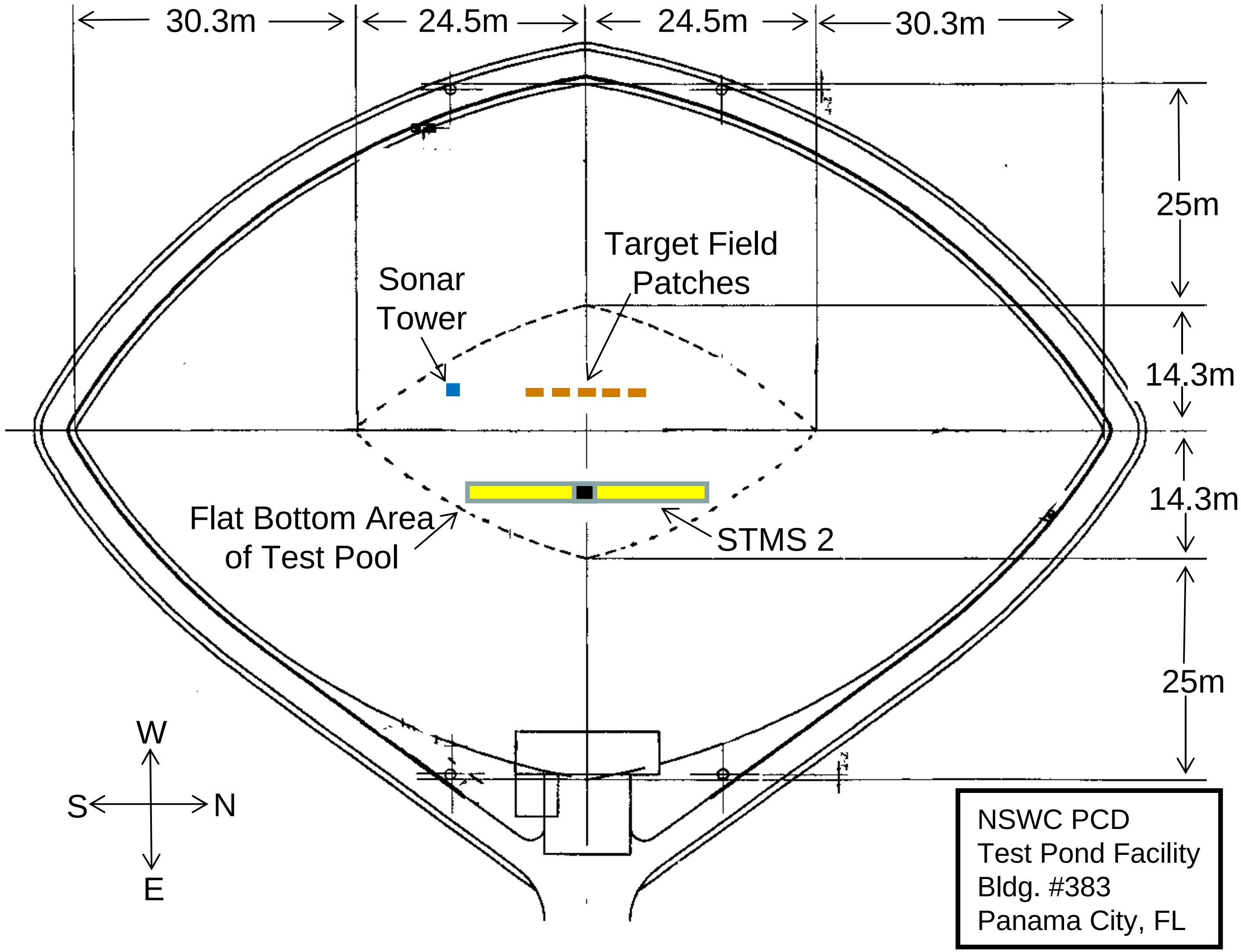
- Understanding the interaction of an acoustic field with a UXO near a water-sediment interface over large frequency and aspect angle ranges.
- Developing an inventory of acoustic responses for various UXOs, which can be used to validate propagation and scattering models.
- Collecting both monostatic and bistatic synthetic aperture sonar (SAS) data from several targets. These data can be used
    - in standard SAS imaging techniques,
    - in producing acoustic templates (i.e., "acoustic finger prints"),
    - in developing and testing of classification algorithms.

PondEx10 Environment

Naval Surface Warfare Center, Panama City Division
Test Pond Facility

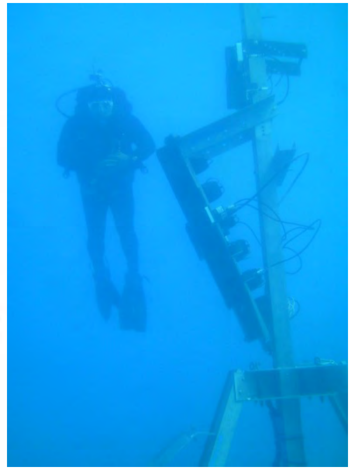
- 9 million gallons of fresh water
- 112 m long, 80 m wide, 14 m deep
- 1.5 m of sand sediment in the center
- Filtered and chlorinated water gives 12 m visibility.

PondEx10 Environment

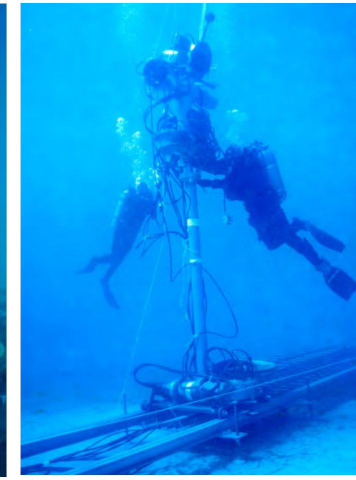


Equipment and Experimental Layout

STMS 2 Rail System



NSWC PCD Rail System

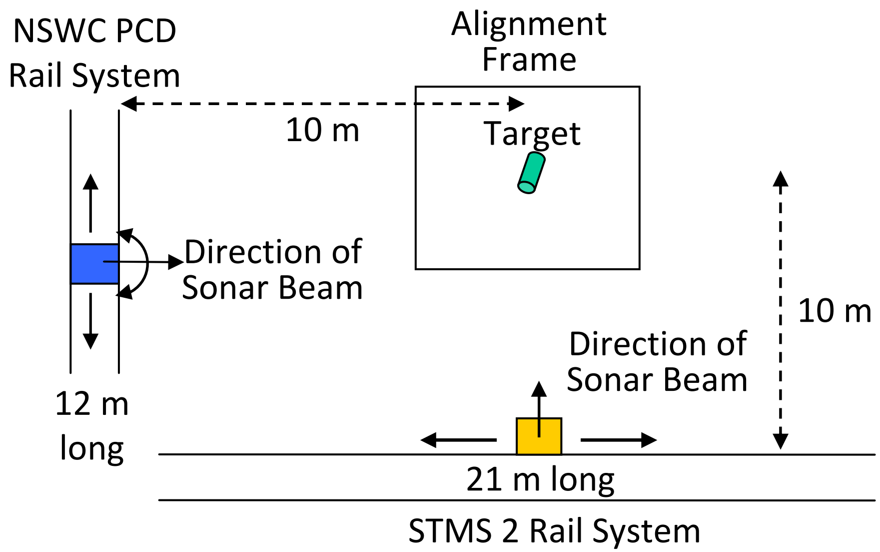


- 21-m rail with 19-m SAS aperture
- Tower travels at 5 cm/s
- Sources and receiving array tilted at 20° or 40° depression angle
- Source waveforms:
  - 1–31 kHz LFM Chirp
  - 30–50 kHz LFM Chirp
- 6-channel receiving array

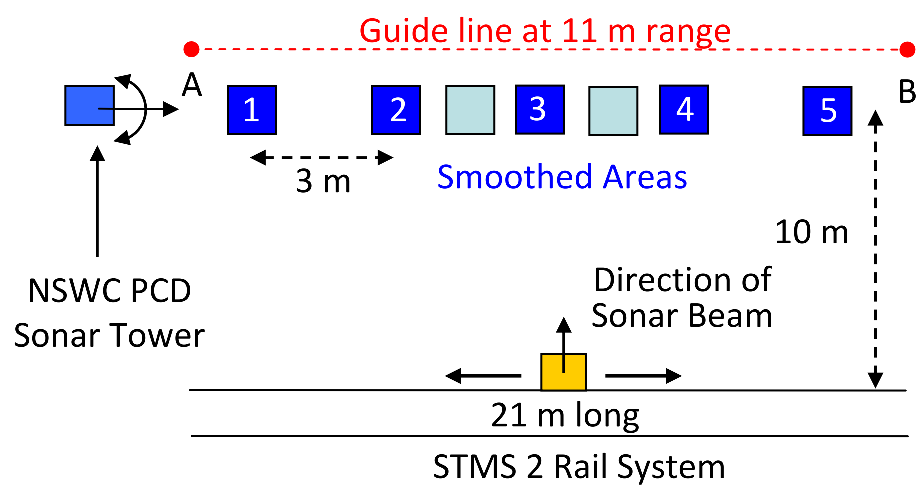
- Sonar tower positioned at 5 and 10 m ranges during PondEx10
- Tilt and pan capability for aligning acoustic axis of receivers to a target
- Receivers:
  - 1–3 composite transducer
  - ITC 1001 hydrophone

Equipment and Experimental Layout

PondEx09 Target Field



PondEx10 Target Field



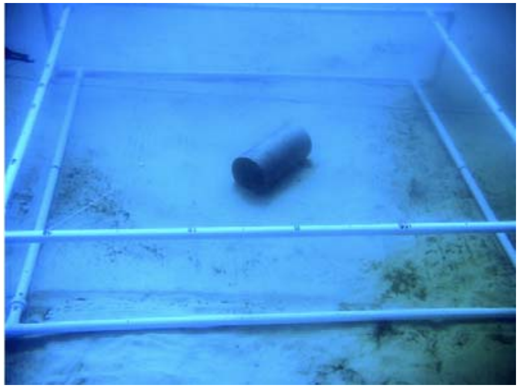
- One target in the target field
- One tower scans while other remains stationary
- Targets rotations: 0° – 80° and 0° – 280° with a 20° increment (depends on symmetry of target)

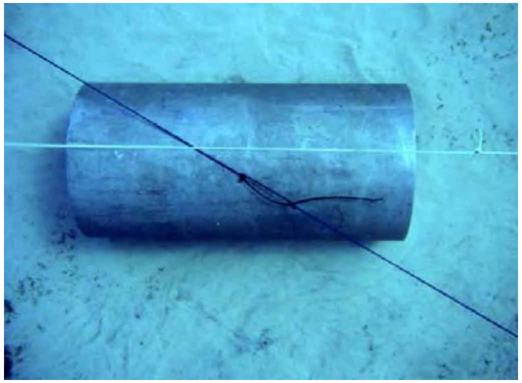
- Multiple targets in the target field
- Adjacent targets separated by 1.5 or 3 m
- Colored patches: 1×1 m^2 smoothed areas
- Targets rotations: 0° – 80°, -80° – 80°, and 0° – 280° with a 20° increment (depends on symmetry of target)

Munitions and Scientific Targets

155 mm howitzer projectile (empty, yellow UXO)
81 mm mortar (filled with cement)
152 mm TP-T round (blue UXO below)
Small aluminum cylinder with a notch
Solid steel artillery shell
Machined aluminum replica of artillery shell
Machined steel replica of artillery shell
Aluminum pipe (1 ft dia., 2:1 aspect ratio)
Solid aluminum cylinder (1 ft dia., 2:1 aspect ratio)
Two rocks (i.e., clutter)

Alignment frame from PondEx09 and cords registered to frame and STMS 2 rail system





Five Broadside Targets in PondEx10 Field

- Machined aluminum replica (top)
- Solid aluminum cylinder
- Machined steel replica
- Aluminum pipe
- Real steel artillery shell (bottom)

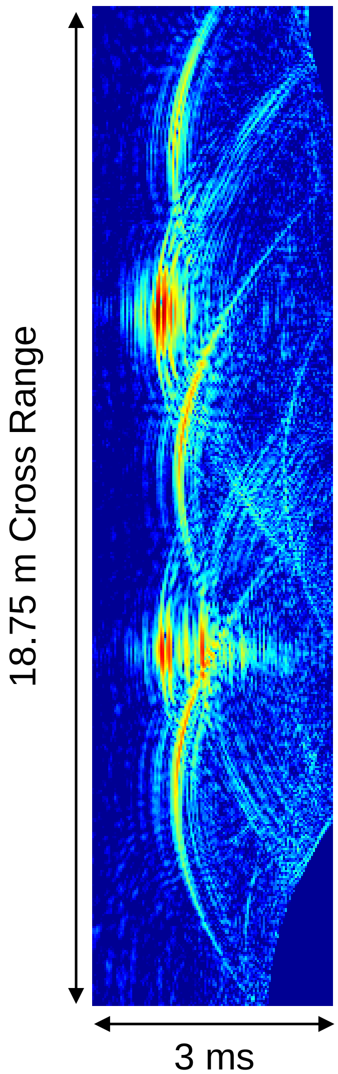
Targets at 10 m range from STMS 2 Rail system

Note interference of the scattered time signals from the targets.

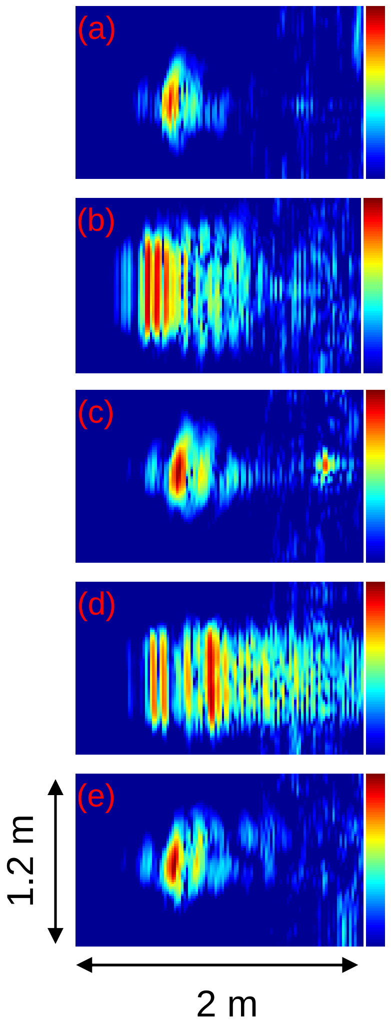
0 to -25 dB color scale

1. Solid aluminum cylinder in (b) exhibits triplet structure that was recently explained by Williams et al, J. Acoust. Soc. Am., **127**, 3356 - 3371 (2010).
2. Pipe in (d) has a strong echo from acoustic energy transmitted through the pipe and reflected from its back wall.
3. Steel UXO in (e) and steel replica in (c) are similar images while an image for an aluminum replica in (a) is dissimilar.

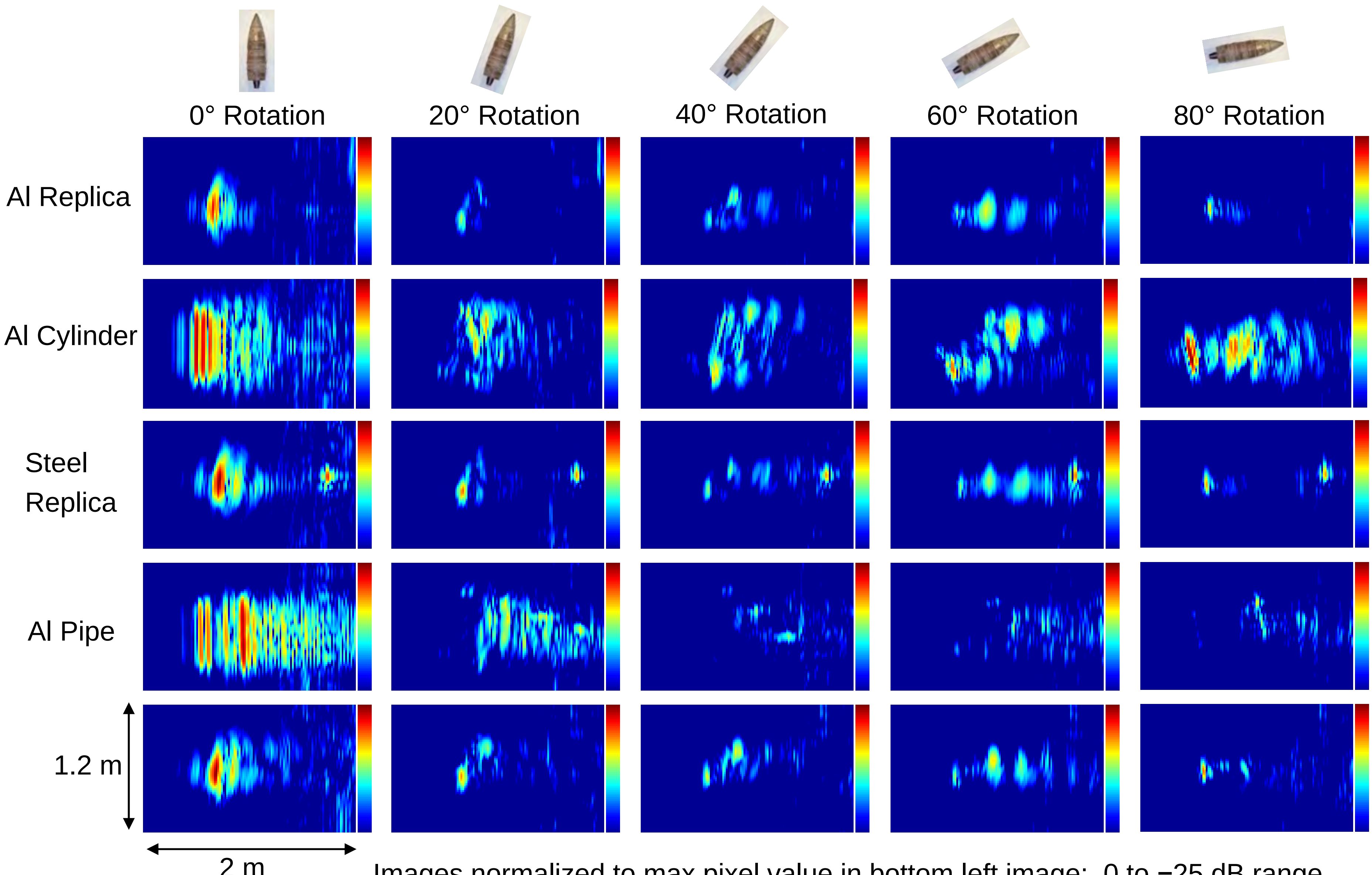
Pulse compressed, Baseband Data



SAS Images

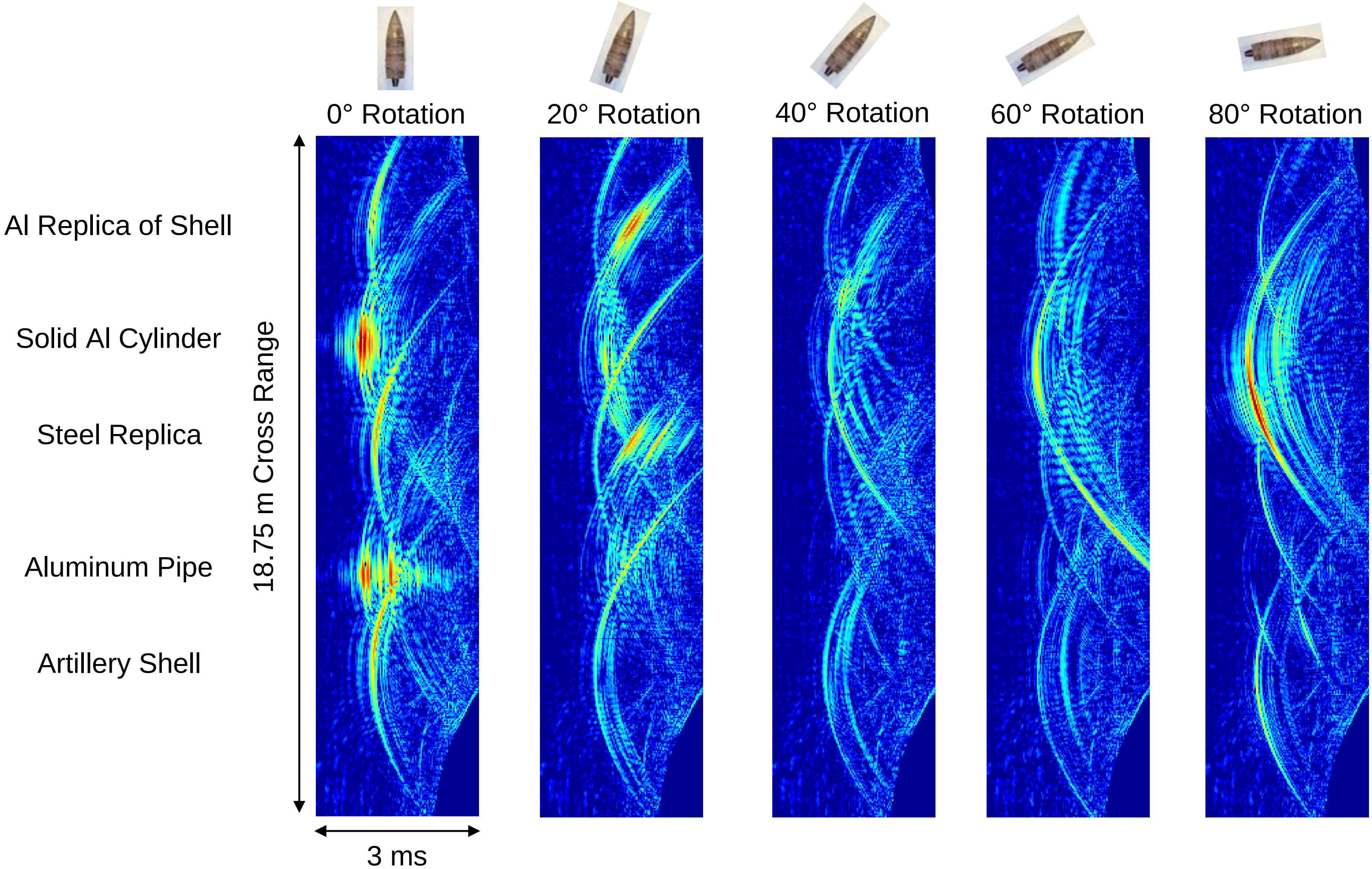


Five Targets in PondEx10 Field: SAS Images



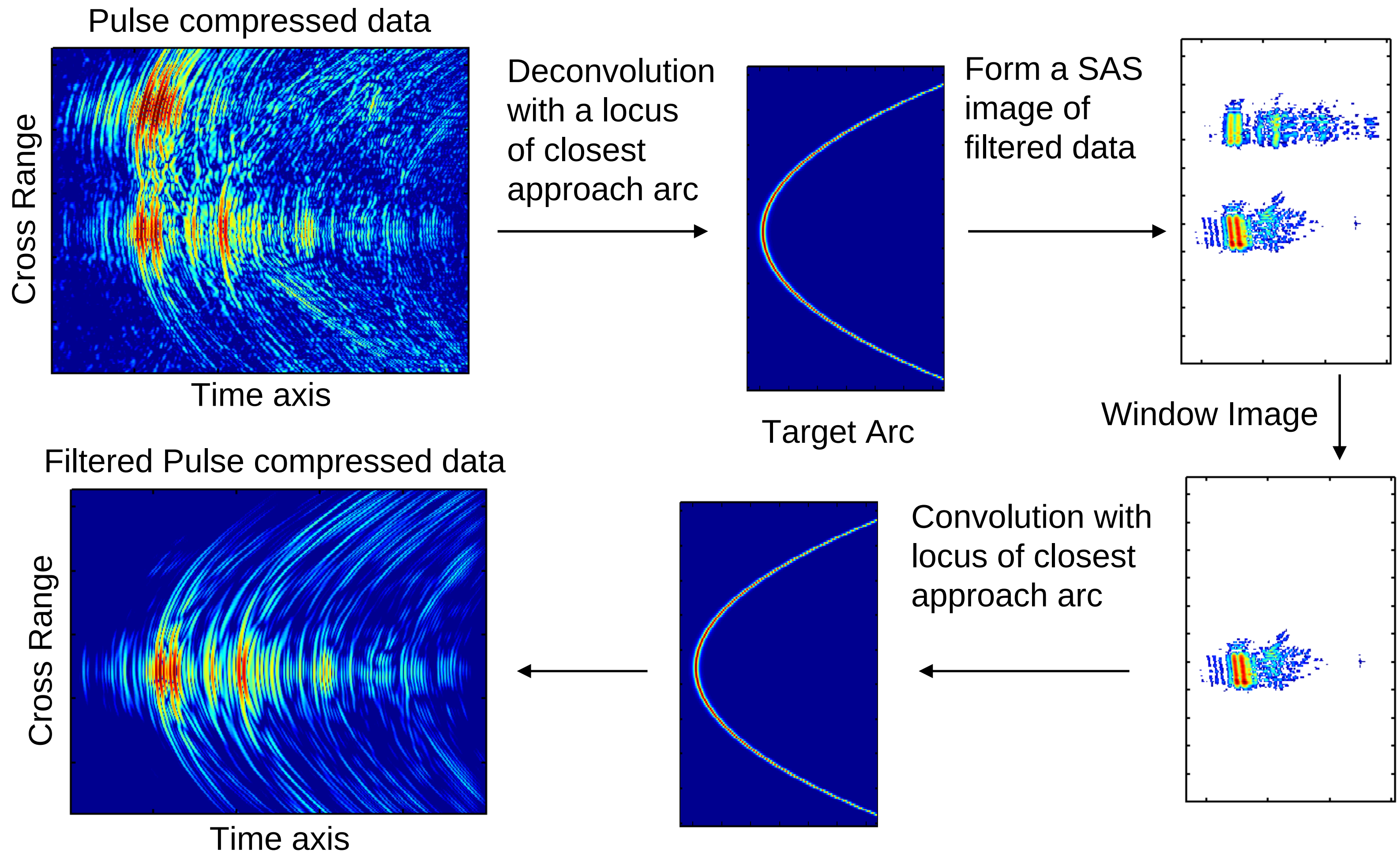
Images normalized to max pixel value in bottom left image: 0 to −25 dB range.

Pulse Compressed Scattered Signals from 5 Targets



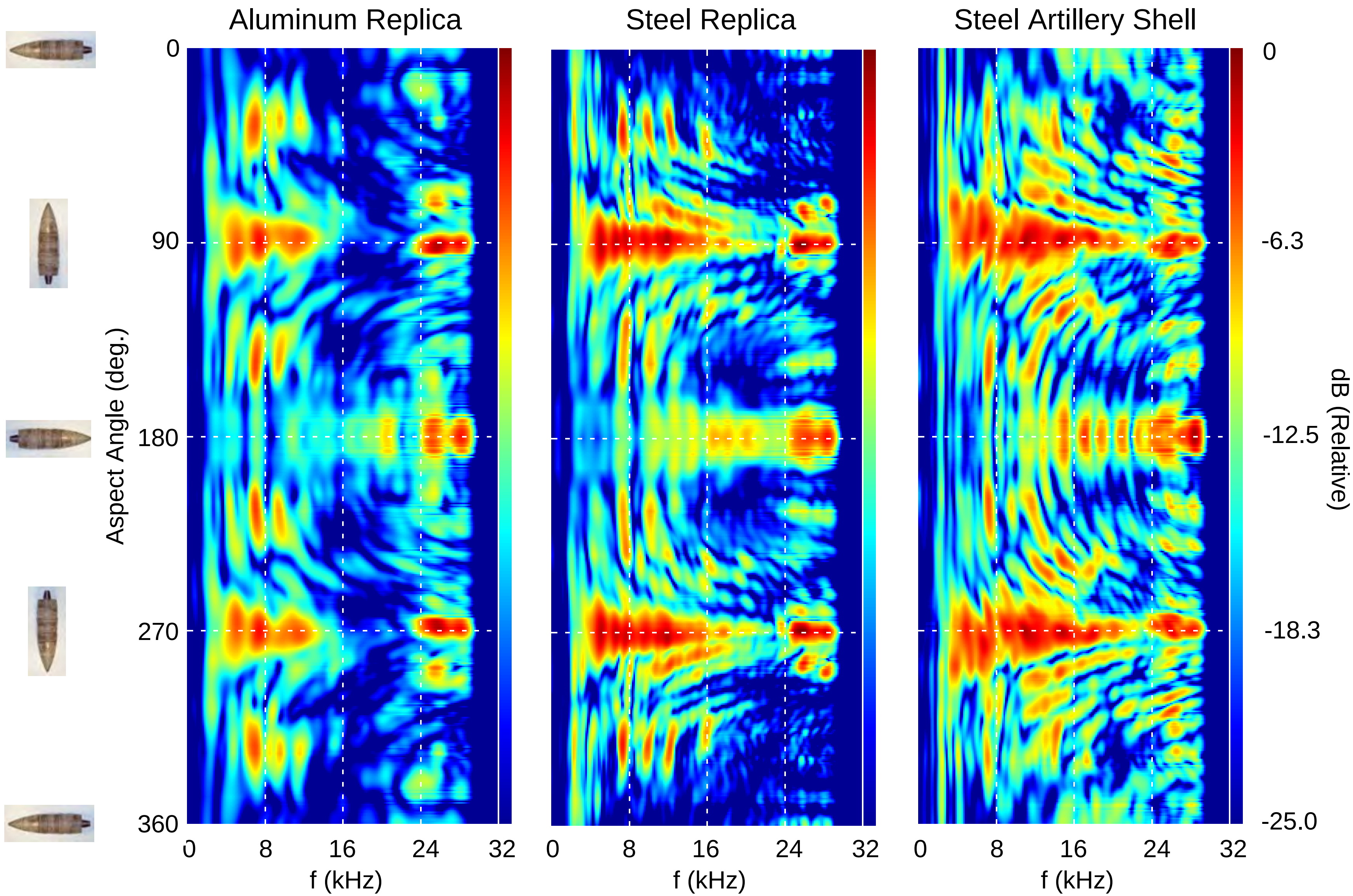
Images normalized to max pixel value in left image: 0 to −40 dB range.

SAS Filtering Algorithm to Resolve Adjacent Targets



The deconvolution/convolution processes are linear transformations. The processing does not alter the information in the isolated signals unless the targets are sufficiently close where multiple scattering may become important.

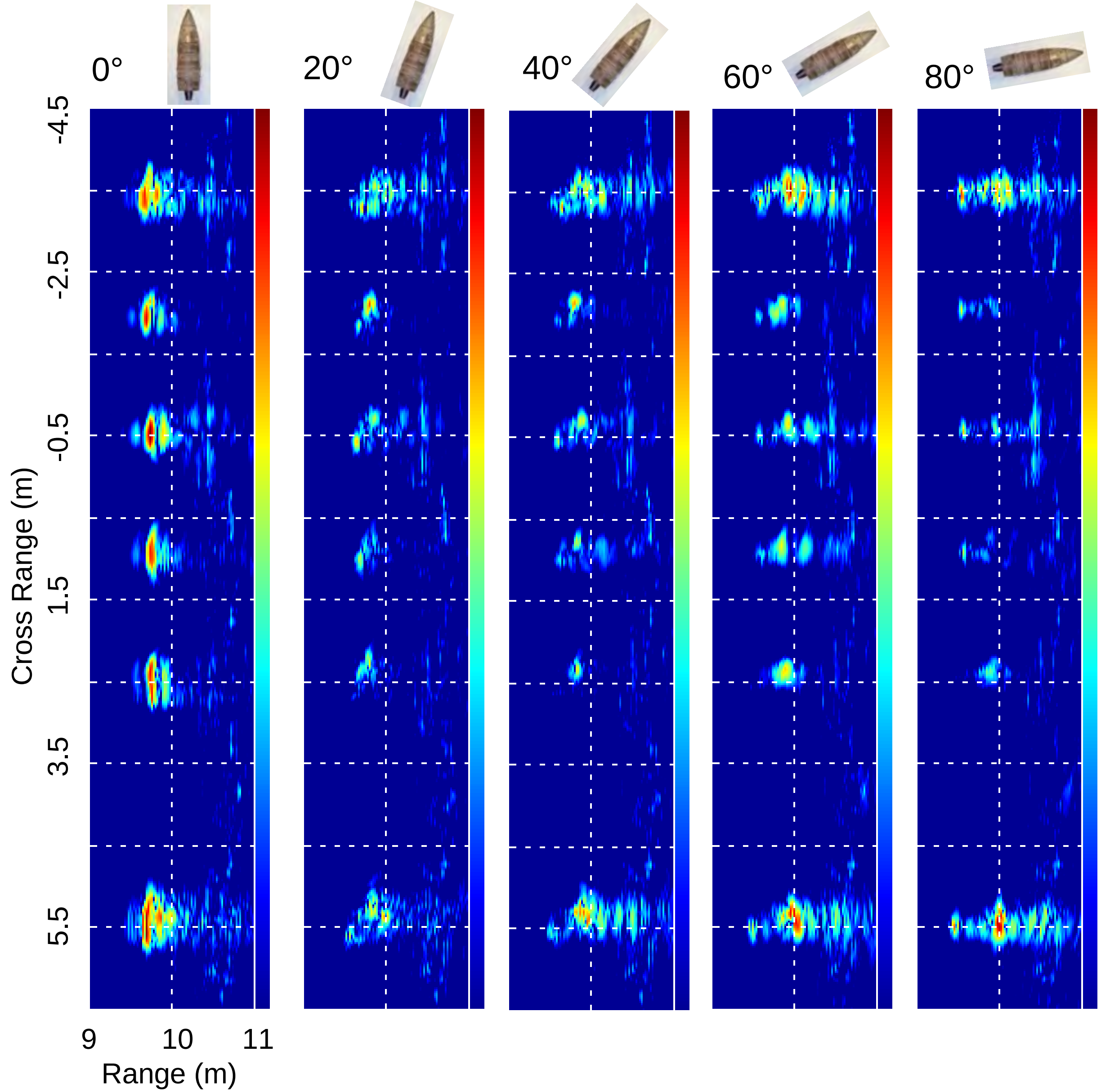
Acoustic Templates after SAS Filtering



Six Targets in PondEx10 Field: SAS Images

Images normalized to max pixel value in left image: 0 to −30 dB range.

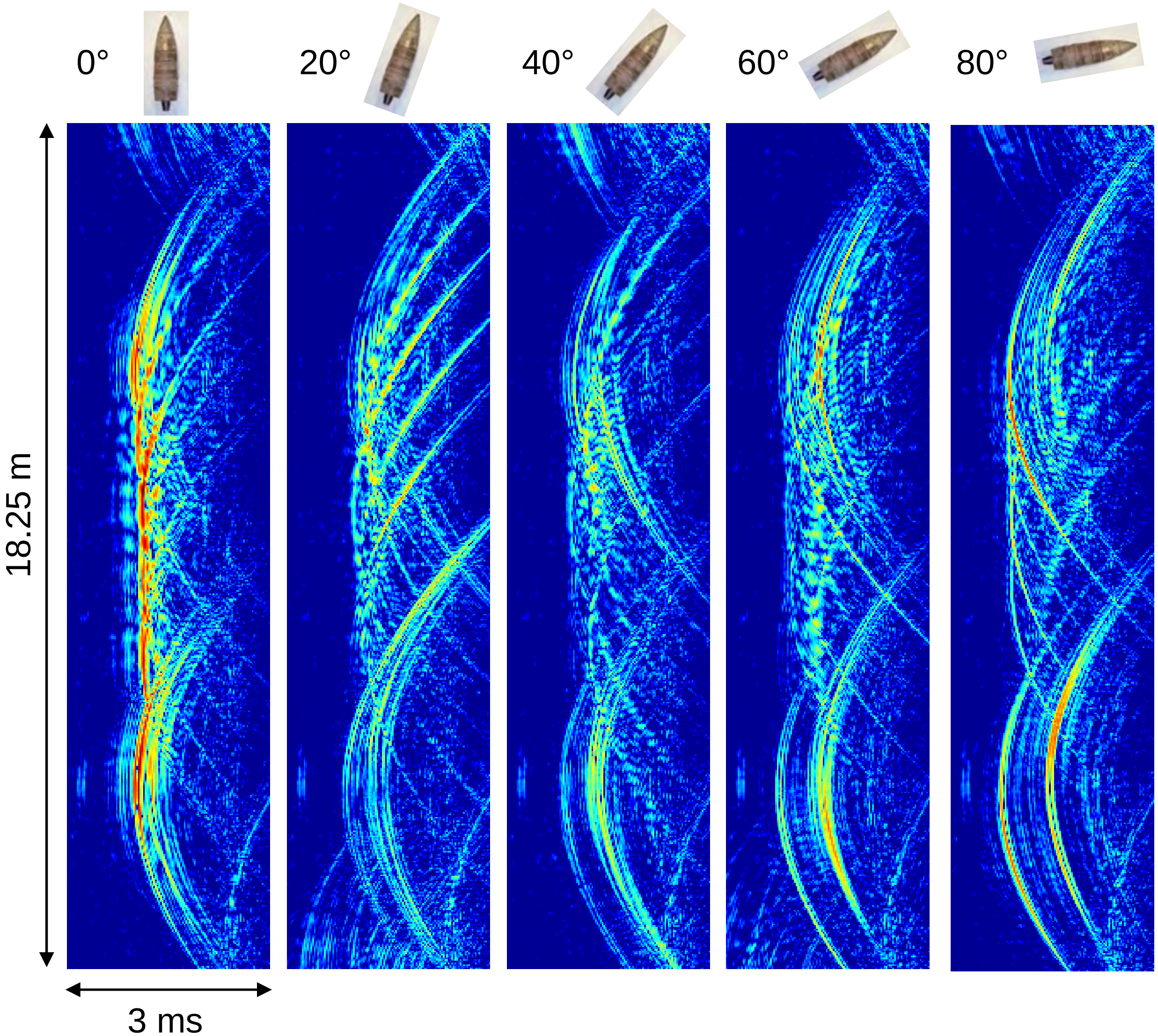
- 152 mm TP-T round (top)
- Small Al cylinder with notch
- Steel artillery shell
- Al replica of artillery shell
- 81 mm mortar (filled with cement)
- 155 mm howitzer shell (bottom)



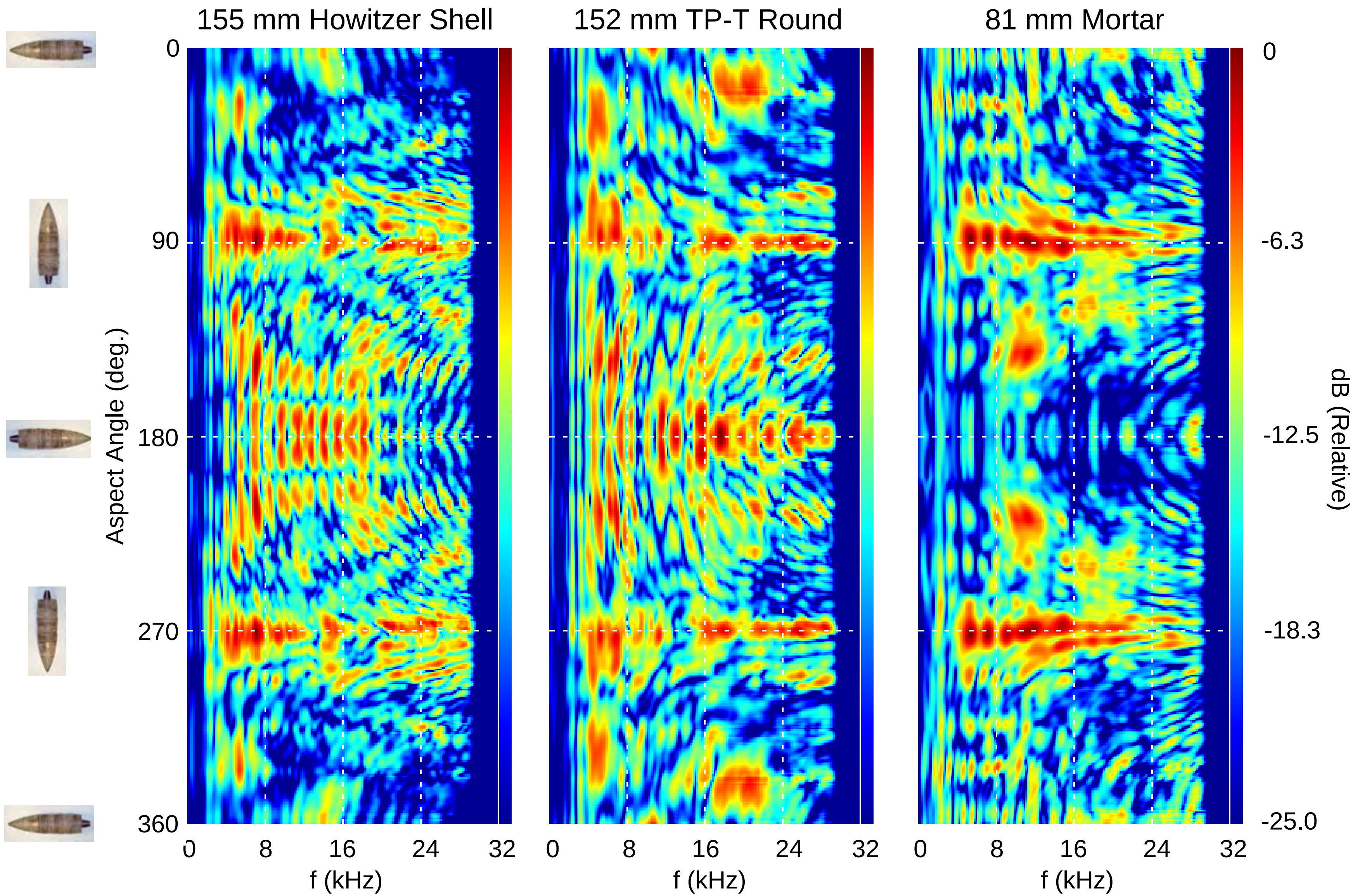
Pulse Compressed Scattered Signals from 6 Targets

Images normalized to max pixel value in left image: 0 to −30 dB range.

- 152 mm TP-T round (top)
- Small Al cylinder with notch
- Steel artillery shell
- Al replica of artillery shell
- 81 mm mortar (cement filled)
- 155 mm howitzer shell (bottom)



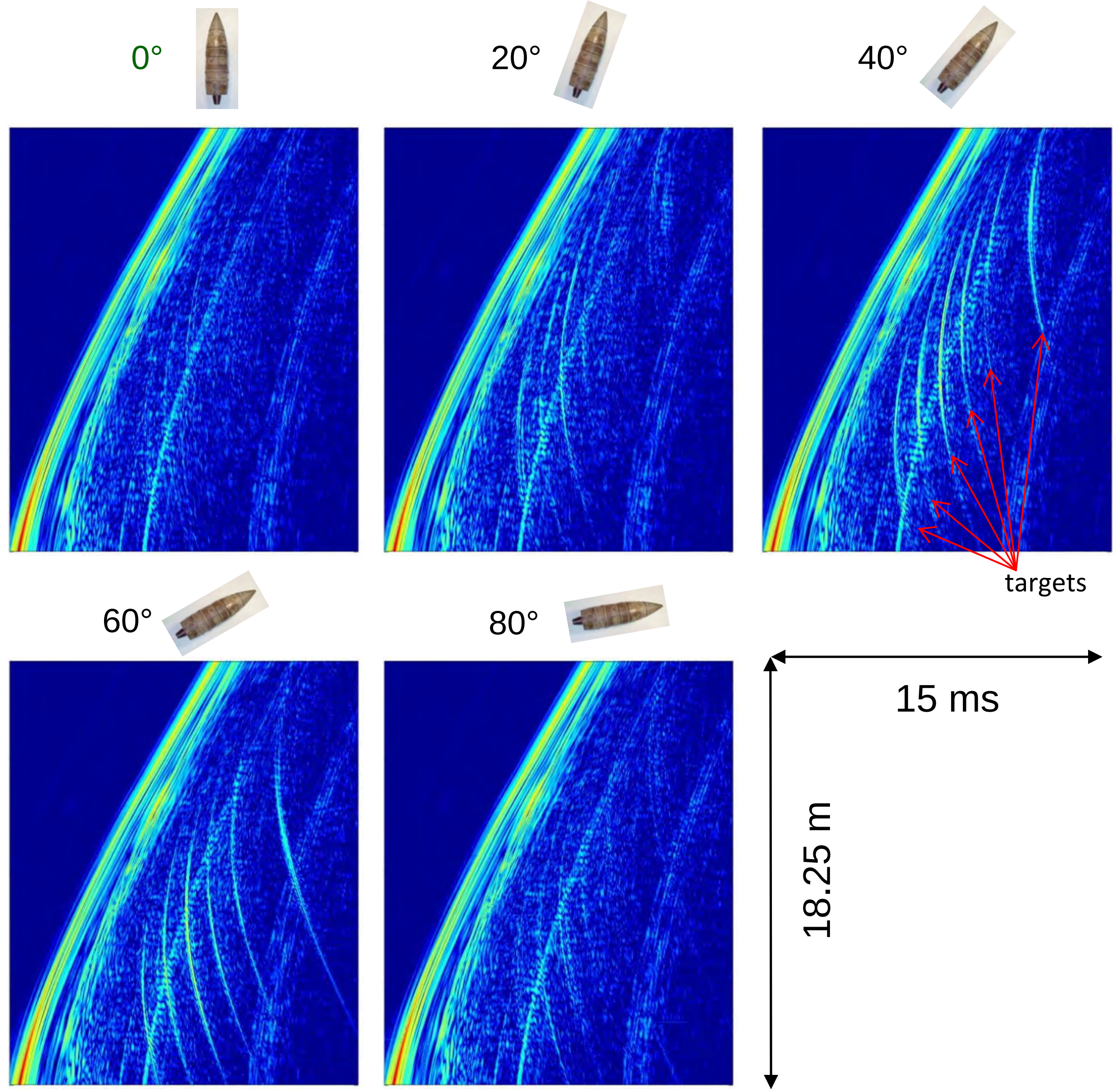
Acoustic Template after SAS Filtering



Pulse Compressed Bistatic Signals from 6 Targets

Images normalized to max pixel value in each image: 0 to −30 dB range.

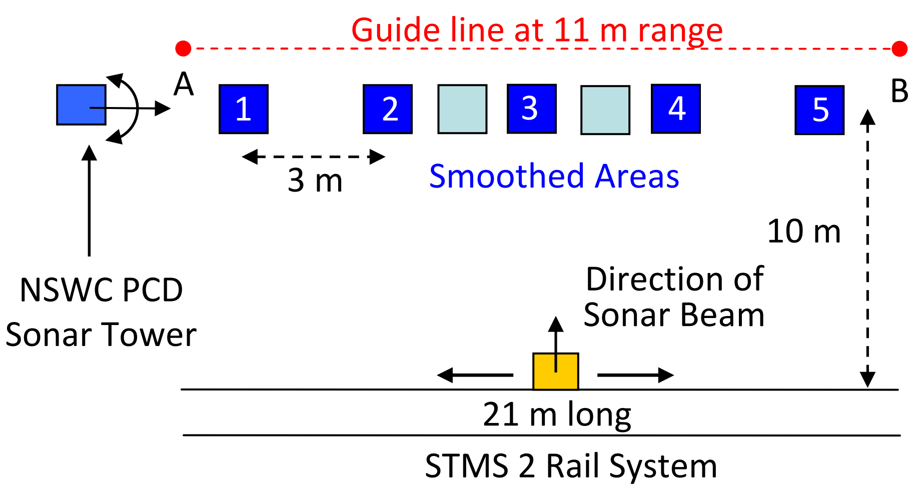
- 152 mm TP-T round (top)
- Small Al cylinder with notch
- Steel artillery shell
- Al replica of artillery shell
- 81 mm mortar (cement filled)
- 155 mm howitzer shell (bottom)

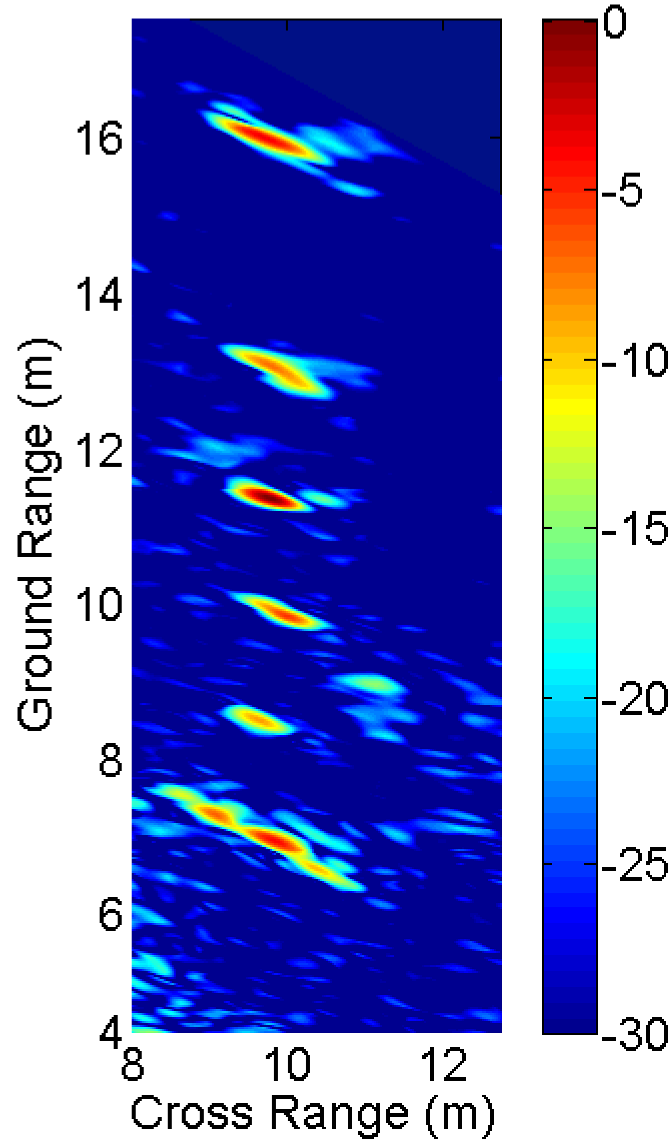


30-50 kHz Bistatic SAS Image

- 152 mm TP-T round (bottom)
- Small aluminum cylinder with notch
- Solid steel artillery shell
- Machined aluminum replica of artillery shell
- 81 mm mortar (filled with cement)
- 155 mm empty howitzer projectile (top)

Targets rotated by 40° with respect to the STSM 2 rail system



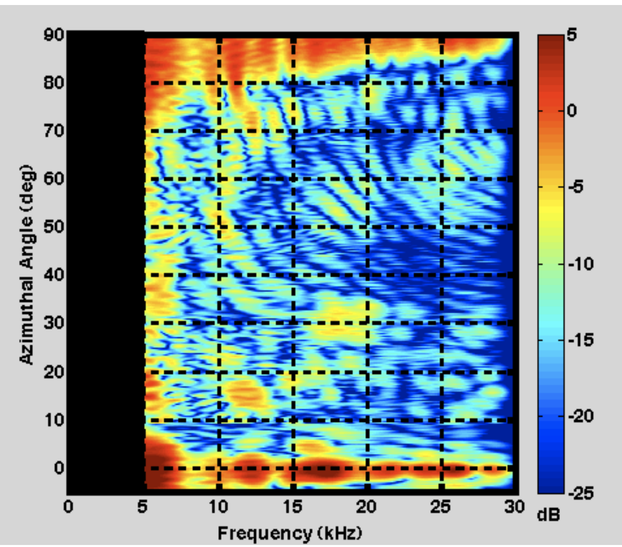


Data-Model Comparison for Solid Aluminum Cylinder

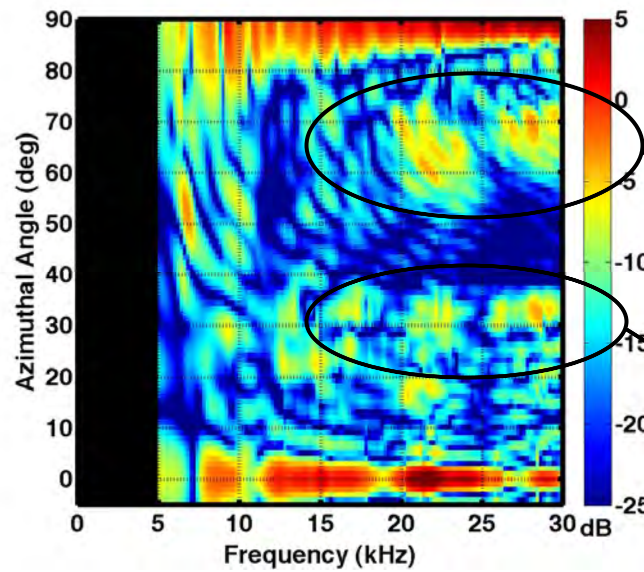
- Comsol™ FEM result via AxiScat Ver 1.1model from NURC
- Features identified using physical acoustics ray models

Normalized Acoustic Templates

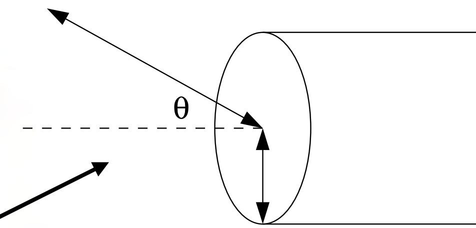
PondEx09



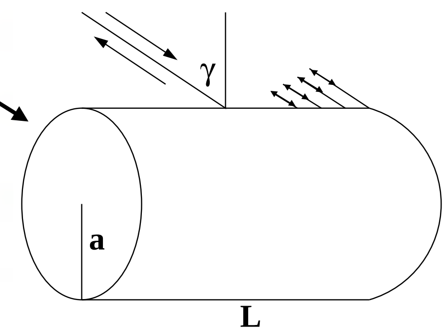
Comsol™ FEM



Face crossing Rayleigh Wave



Meridional Rayleigh Wave

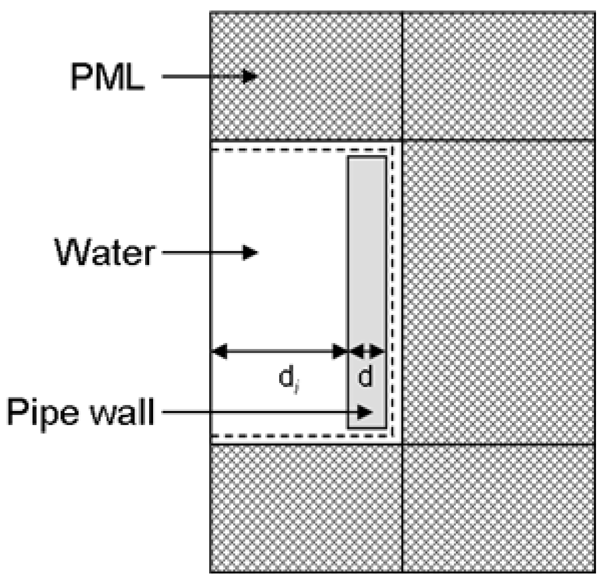


- Broadside orientation at 0°
- End-on orientation at 90°

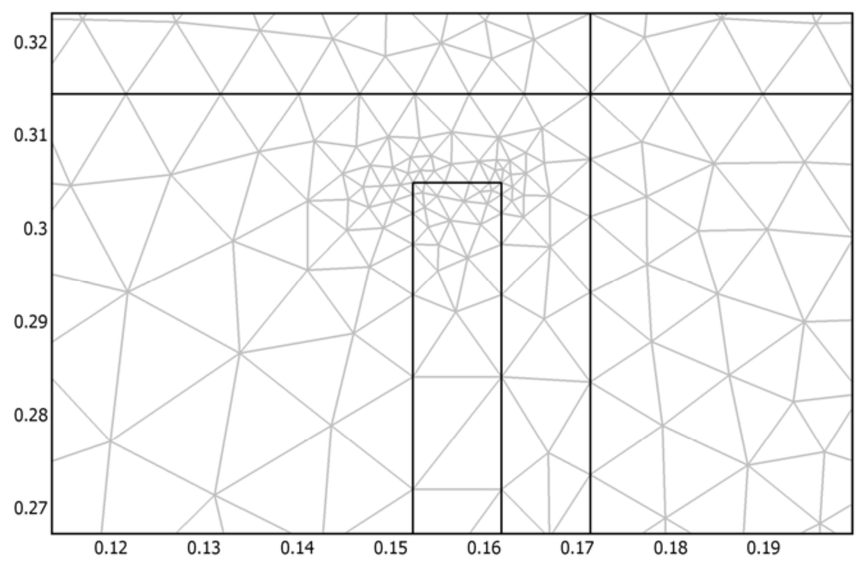
Current State of Finite Element Models

- FE models results for free field and proud solid aluminum cylinder have been compared to data. Williams *et al*, J. Acoust. Soc. Am., **127**, 3356-3371 (2010).
- Under an ONR post-doc, Dr. España has modified the model of Williams et al to simulate free field and proud scattering from an aluminum pipe.
- Computational meshes for the steel artillery shell and its aluminum and steel replicas have been developed with and without the surface feature (i.e., ‘v’-shaped grooves).

Computational domain

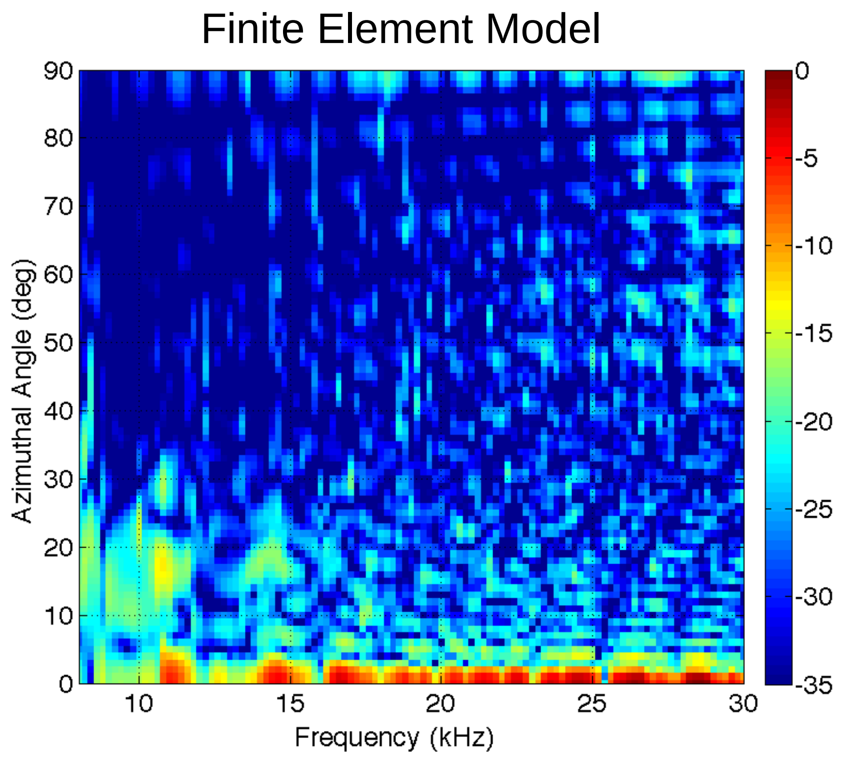


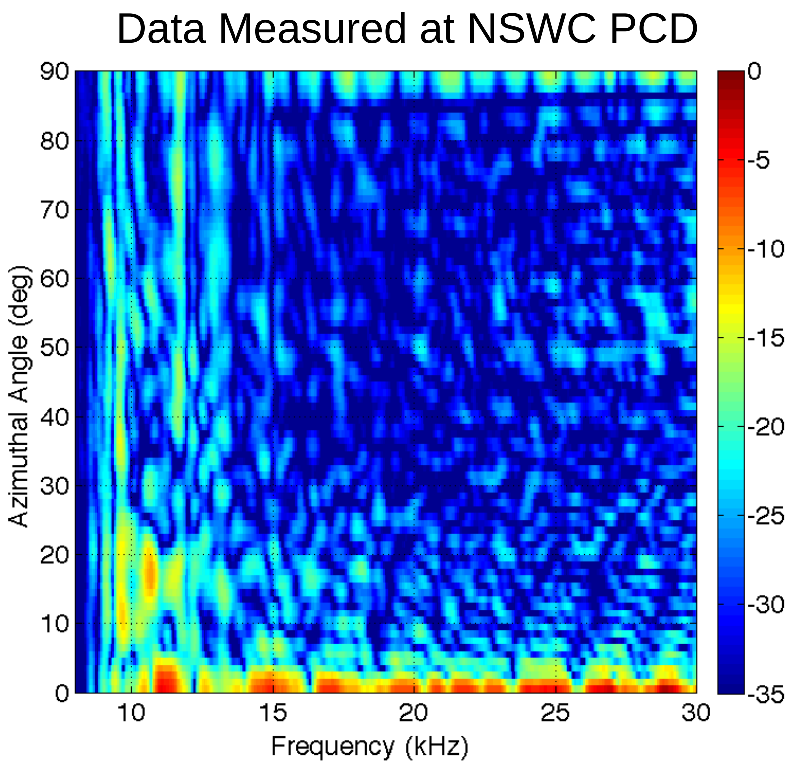
Uniform 1 cm mesh
Refined around corners to 1 mm



Current State of Finite Element Models

FE Model - data comparison for an aluminum pipe (2 ft long, 1 ft diameter, 3/8 inch wall thickness) suspended in the free field.





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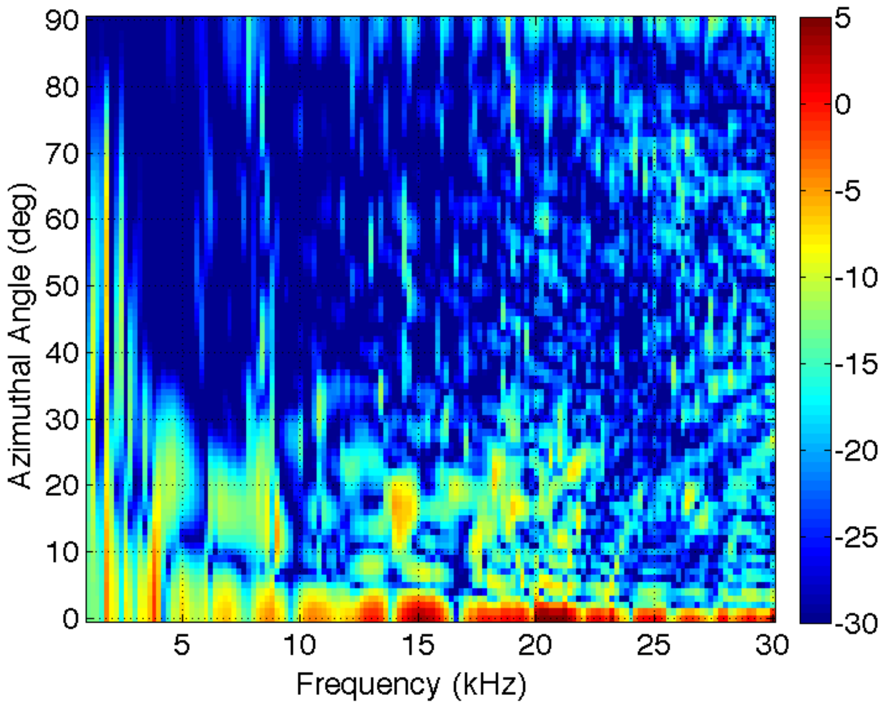
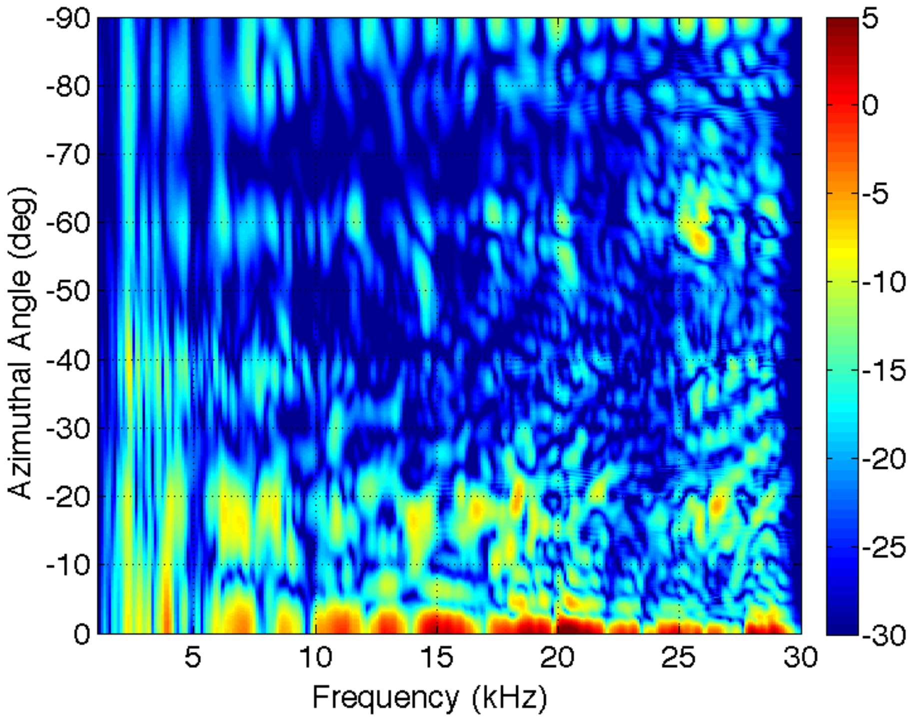
Current State of Finite Element Models

FE Model - data comparison for an aluminum pipe (2 ft long, 1 ft diameter, 3/8 inch wall thickness) lying proud on a flat water-sand sediment interface.

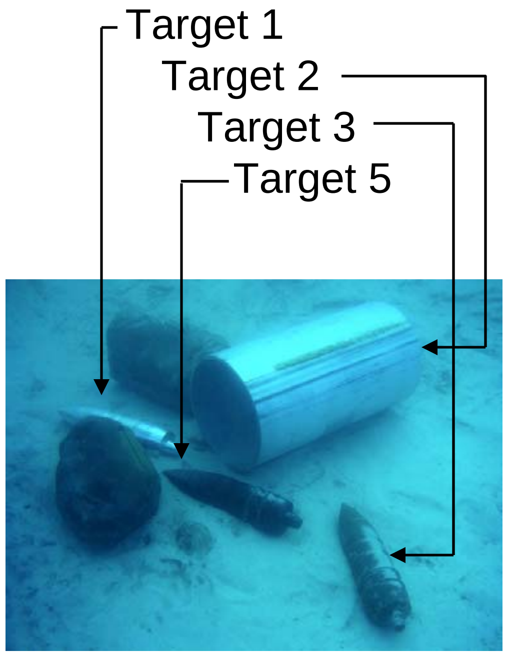
Finite Element Model

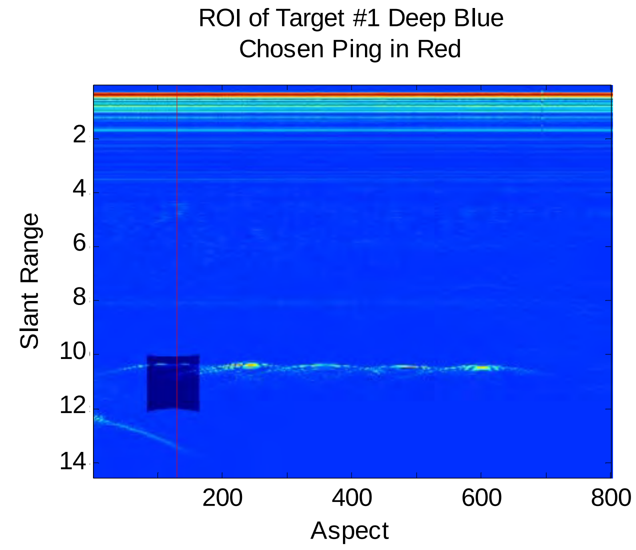


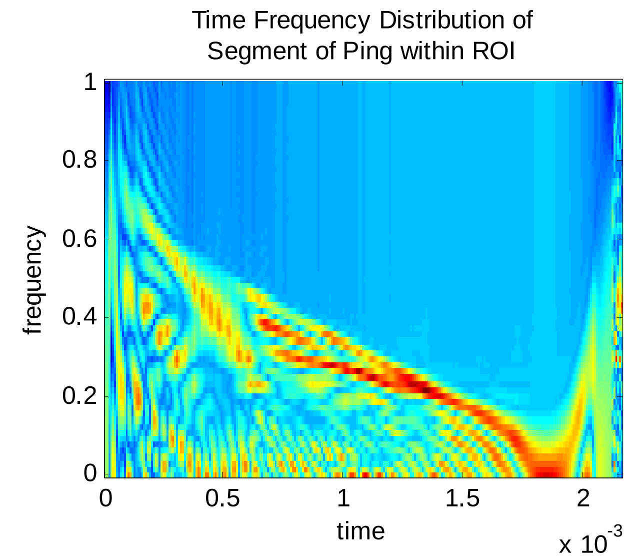
PondEx10 Data

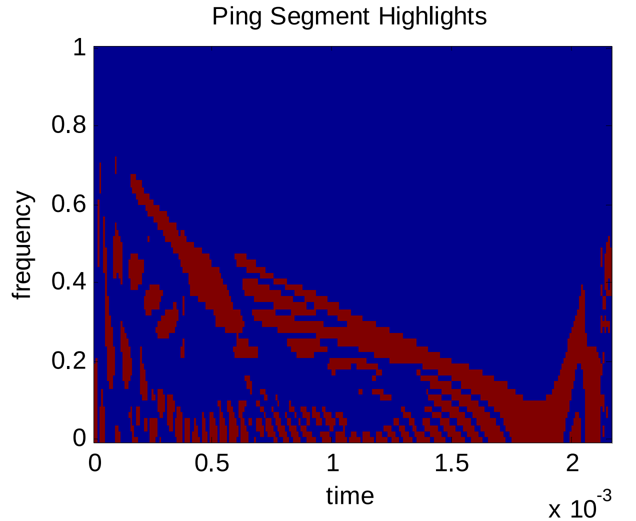


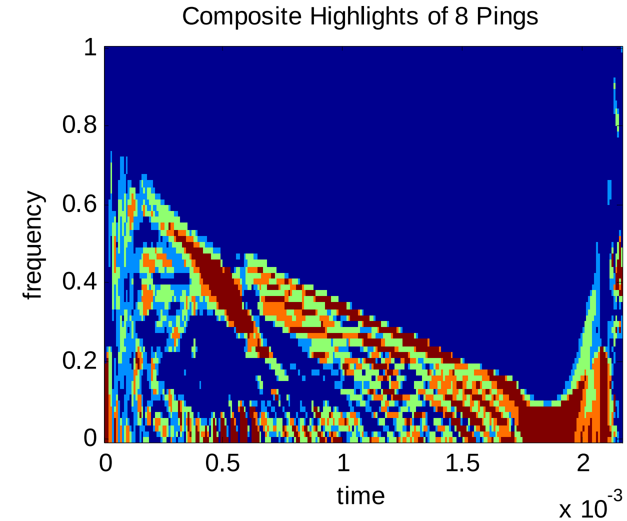
Class Separation of UXO Using Time-Frequency Features



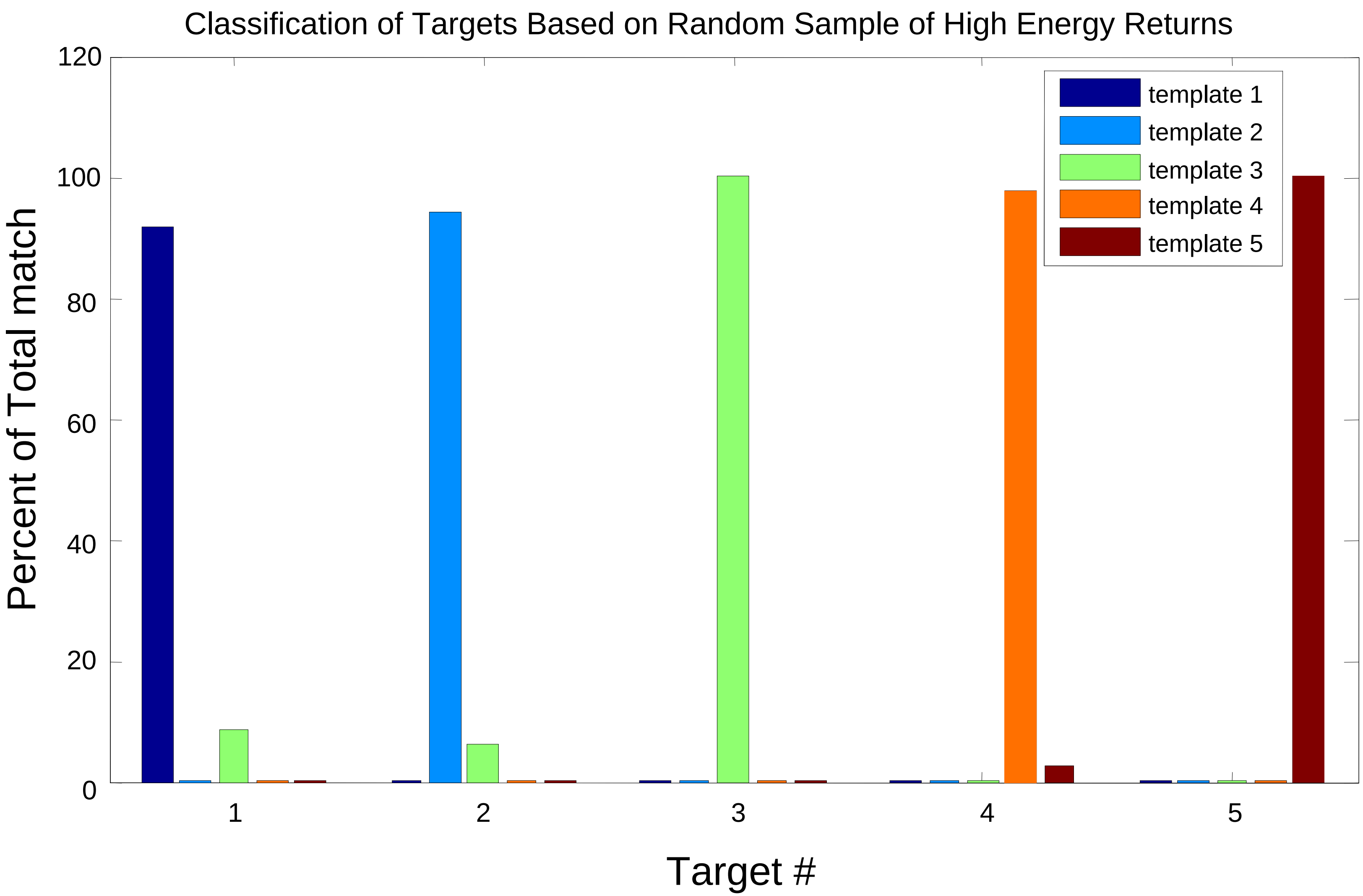






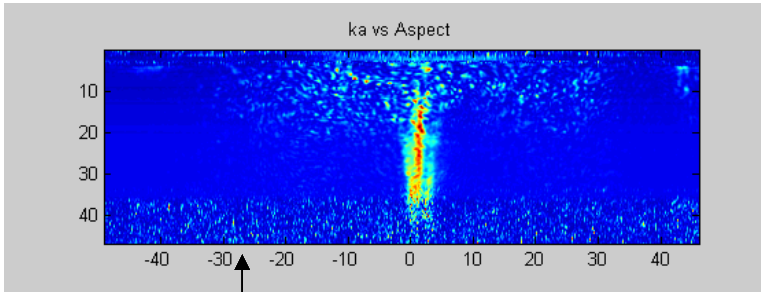


Class Separation of UXO Using Time-Frequency Features

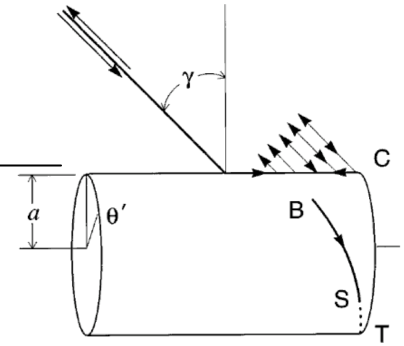


Class Separation of Cylindrical Targets Using Features

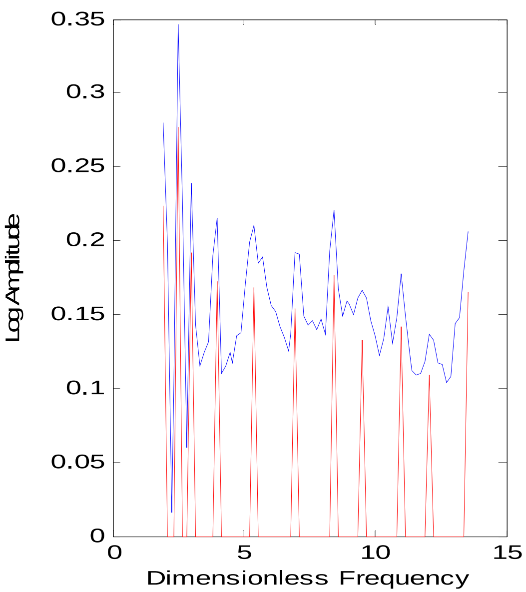
Processed buried target data



Aspect = -27°
Physical interpretation of structure: helical wave



- Unique physics-based features deduced from spectra and knowledge of target length
- Results fed into spectral algorithm that identifies peaks associated with the observed phenomenon



Blue: Data at -27° aspect

Red: Identified peaks by algorithm which looks for nearly harmonically related peaks

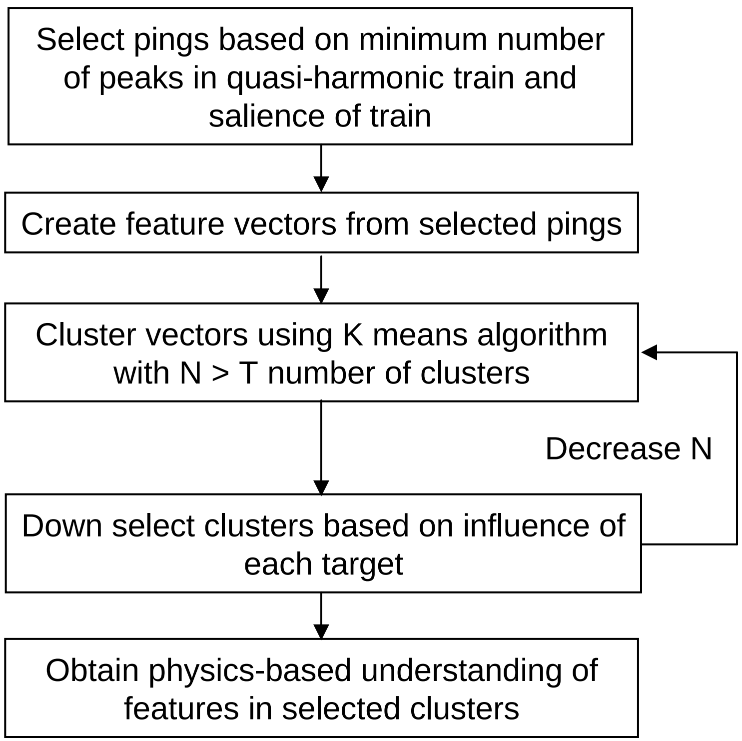
4 cylinders with 2:1 aspect ratio

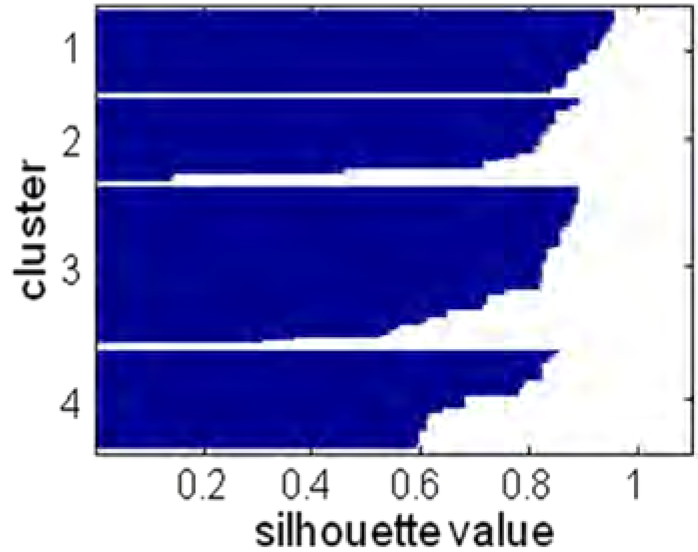
Create feature vectors consisting of 5 parameters:

- number of quasi-harmonic peaks,
- start frequency,
- separation between peaks,
- a salient factor (value dependent on relative size of peaks relative to the background),
- aspect angle.

Class Separation of Cylindrical Targets Using Features

Process for using elastic information in sonar data to discriminate between 4 cylindrical targets with the same size and shape.





Silhouette plot of four clusters in 5 dimensional feature space demonstrate good class separation using chosen feature vector in a k-means algorithm.

If the *silhouette value* is close to 1, it means that the sample is “well-clustered” and it was assigned to an appropriate cluster.

Summary

- Monostatic and bistatic acoustic scattering data sets over a wide frequency range have been processed with standard SAS imaging algorithms and acoustic templates have been generated.
- Targets included 6 UXO, 3 cylindrical targets, and 2 rocks.
- The SAS filtering algorithm has been found to be a robust means for isolating the scattered signal from an UXO in a cluttered environment.
- SAS images and acoustic templates suggest rich elastic responses are present on the UXO and these may be used in detection and classification algorithm.
- On-going finite element simulations are compared and validated against data.
- Bistatic SAS images have been created, but the data sets have yet to be exploited in a classification scenario such as acoustics templates.

Thank you for your attention.